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EXPERIMENTAL STRENGTH ANALYSIS OF RIVETED JOINTS USING BLIND RIVETS

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Abstract

This article presents results of experimental investigations of the lap blind riveted joint. The main goal of the work is determination of destructive load of the blind riveted joints. The blind rivets were originally used in the aircraft structures where access to both sides of the riveted structure is impossible. Blind rivets are now commonly used in many branches of industry because of their low cost. Moreover, the riveting process is uncomplicated. There are many publications about analysis of strength of solid rivets in the research literature. However, the strength analysis of the blind rivets was rarely undertaken. There is the research gap in the analysis of both the strength and the load capacity of blind riveted joints. The influence of selected geometrical parameters of the joint on the stress distribution and the destructive force was not widely described in literature. The first part of the work presents a review of standards and publications related to stress and strength analysis of blind riveted joints. The next part of the study describes experimental investigations of joints. The examined specimens were made out of AW 2017 aluminum alloy, cut from 1[mm] thick sheet. Investigated blind rivets were made out of aluminum alloy. The lap joint with one rivet and the single row five-rivet joint were investigated. Moreover, the different size of hole chamfer were considered. The experimental tests were performed with the use of Zwick-Roell tension machine. The main results of experimental investigations are ultimate shear load diagrams. The influence of both the hole chamfer and the number of rivets on destructive force and shear diagrams of blind riveted joints were in detail analysed. After shear tests, the fractured rivets were magnified in order to explain the failure phenomenon of blind rivets. In the future research works the obtained results will be used in strength analysis of the blind riveted joints using the finite element method.

Keywords: *blind riveted joint, experimental investigations, shearing test, destructive force, chamfers*

1. Introduction

Riveted joints are old, but still widely used connections in many branches of industry, including the aviation. In classic type of riveted joints, the solid rivets are used, but usually, two-sided access is required during head forming. In the aviation industry, the blind rivets are used for riveting of closed profiles (wing, tail, fuselage), where access to both sides of the riveted structure is impossible. The advantage of blind rivets joints is relatively low cost, uncomplicated riveting process (use of a hand-riveting tool) and the ability to dismantle and reassemble the joined elements.

The main goal of the work is determination of destructive load of the blind riveted joints. In this study the influence of both the hole chamfer size and the number of rivets in joint on destructive force and shear diagrams of blind riveted joints were additionally analysed.

2. Review of literature

Riveting is a traditional but still widely used method of connecting of the structural elements. Rivets are commonly used in many branches of industry because of their low cost. Moreover, the riveting process is uncomplicated. Thin-walled profiles are most often joined by blind rivets, which have the additional advantage of making a connection with one-sided access.

For many years, several studies were related to increase of the strength and fatigue life of riveted joints. In the past, these investigations were mainly based on experimental tests because the analytical description of phenomena occurring in riveting or shear processes is very complex.

The attention in many research works was focused on rivet head forming. In study [5] the effect of rivet squeeze force on the rivet driven head dimensions, rivet hole expansion and impact of the squeeze force on distributions and values of residual stresses were analysed. Most publications are related to solid rivets and repair of damaged riveted joints. Another research studies focus the attention on full rivets. In the work [13], the authors analysed the influence of join geometry on its fatigue life. In mentioned work, authors presented new methods of repairing damaged riveted joints.

In research literature, the problems of maximum load, stress distribution or fatigue life of riveted joints were often described. In majority of works, the authors analysed the strength of riveted joints with various numbers of rivets, including the blind rivets. In the experimental shearing tests the maximum force, displacement, and influence of a number of rows (1-2 rows) and rivets in a row (1-2 rivets) on joint strength were often examined [12]. Additionally the influence of the number of rivets and rows on the joint destructive force was analysed.

In the case of blind rivets, the experimental analysis of impact of thermomechanical load on the strength of the joint was performed [10]. The authors showed how the load capacity of the riveted joints drastically decreases with the temperature increase during the shear test. Another paper [11] presents a study in which the possibility to replace traditional riveted joints with a blind rivet was considered.

The geometry and the construction parameters of joint have an influence on its strength. In the publication [14] authors analysed deformation of the rivet, the rivet hole and the influence of selected geometrical parameters on the stress distribution and fatigue life of joint. The test results showed that the change in sheet thickness has a large influence on both the stress distribution and the strength of the riveted joints [15].

In other publications, the results of experimental analysis of riveted joints were compared to results of numerical simulations. In work [16], the stress distributions and the ultimate load capacity during shear test in different combinations of blind rivets were investigated.

The latest publications on blind rivets are devoted to analysis of friction stir blind riveting (FSBR) as a new mechanical joining method. In FSBR, the blind rivet is driven toward the work materials with a high-speed rotating tool. The authors of work [8] showed that joints produced by the new method have approximately 20% higher strength than the joints made by conventional blind riveting. In the study [7] the heat transfer of the FSBR process and its influence on joint strength were investigated. Experimental tensile tests and shear tests of riveted joints showed that the maximum loads of FSBR joints are higher than joints obtained in conventional riveting process [9]. In the paper [6] is shown that the spindle speed and feed rate have significant effects on the force peak, the torque peak.

Presented above literature review showed that, there is a limited number of research works related to blind rivets. The literature on blind rivets refers only to experimental and numerical investigations of the new automatic riveting method. However, the strength analysis of the blind rivets was rarely undertaken. There is the research gap in analysis of the strength, the destructive load, and the influence of geometrical parameters on strength of the blind riveted joint.

3. Experimental static tests of riveted joints

3.1. Specimens – geometry and material properties

The specimens used in static tests of joints were made from 1 mm thick sheet. The sheet was made out of EN AW 2017A aluminum alloy. Mechanical and chemical properties of AW 2017A alloy are presented in Tab. 1-2. The joints were performed according to following standards: EN 1993-1-8, EN ISO 14589: 2000 [3, 4].

Tab. 1. Mechanical properties of EN AW 2017A alloy [1, 2]

Material name	Young modulus, E GPa	Yield stress, $R_{p0,2}$ MPa	Ultimate tensile strength UTS, MPa
Aluminum alloy EN AW 2017A	179	288	440

Tab. 2. Chemical composition of aluminum alloy AW 2017A [1, 2]

Values are in weight percentages (%)							
Ti	Si	Fe	Cu	Mn	Mg	Cr	Zn
0.04	0.64	0.4	4.2	0.62	0.76	0.05	0.18

3.2. Description of blind rivet

Nowadays, producers offer many kinds of blind rivets. In order to joint preparation, the conventional, and most commonly aluminum blind rivets were used. Geometry of blind rivet is presented in Fig. 1. During riveting process, the mandrel moves down and in consequence, the upset head is created (Fig. 2).

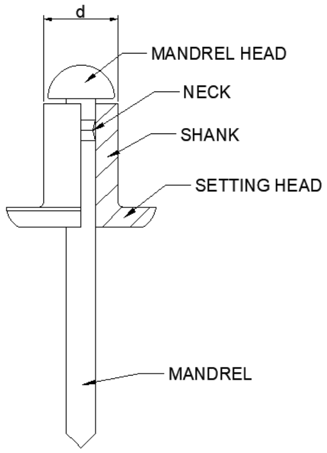

Fig. 1. Geometry of blind rivet

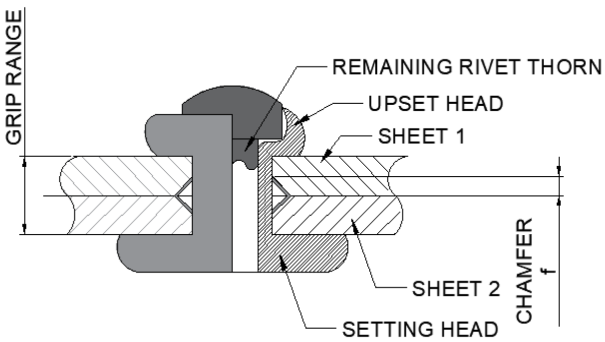

Fig. 2. Geometry of joint

3.3. Specimens preparation

The dimensions of specimens were shown in Fig. 3. Specified combinations of rivet configurations, selected geometric parameters of joints and size of hole chamfer were presented in Tab. 3. Size and location of the hole chamfer is presented in Fig. 4.

(a)

(b)

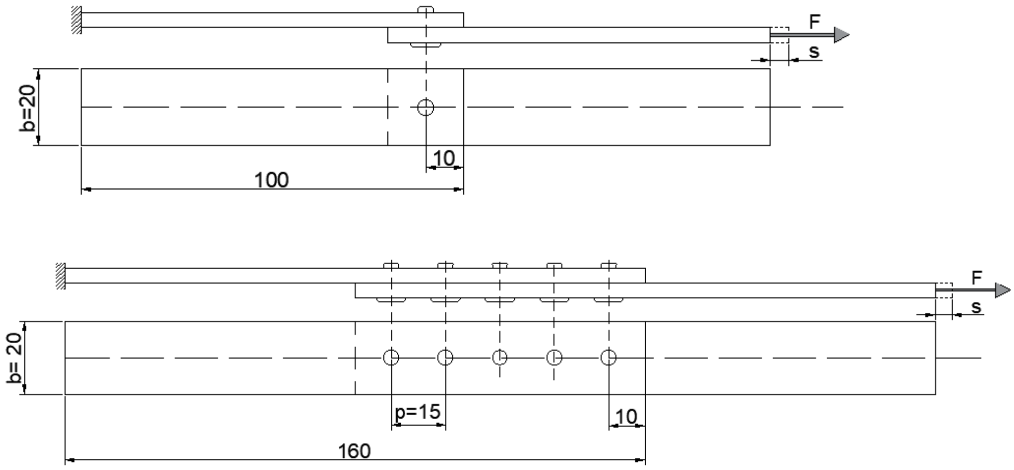

Fig. 3. Geometry, load and boundary condition of joints used in experimental analysis; one-rivet lap joint (a). Single row five-rivet lap joint (b)

Tab. 3. Geometry of joints used in experimental analysis

Working symbol of joint	Width of sheet b [mm]	Number of rivets	Rivet spacing p [mm]	Size of hole chamfer f [mm]
A0	20	1	-	0
A01	20	1	-	0.1
A03	20	1	-	0.3
A05	20	1	-	0.5
A07	20	1	-	0.7
B15	20	5	15	0
B30	20	5	30	0

a) *b)*

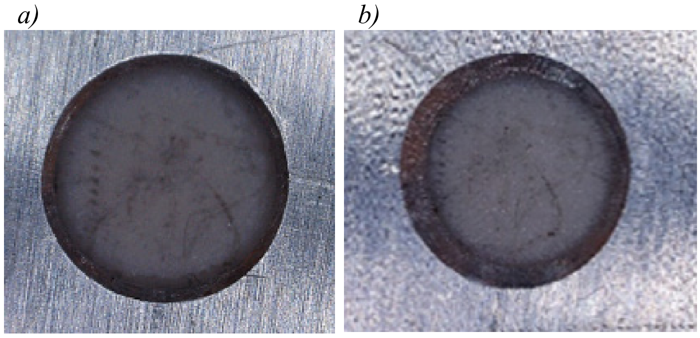

Fig. 4. The hole with 0.1 mm (a) and 0.5 mm (b) chamfer

3.4. Static tests of joints

Before the static tests, the joints were numbered and labelled (Tab. 3). Such prepared joints have been subjected to the shear tests until damage of rivet. The static shear tests were performed using the Zwick-Roell tensile machine. During the test, the force and displacement of grips were monitored. Static tests of joints were performed for the same conditions (speed of traverse was equal to 7 mm/min).

4. Results of experimental investigations

During tests of joints, the values of force F and displacement s (Fig. 3) were saved. It enables to create the shear load diagram of the joint.

As seen from Fig. 5, the size of hole chamfer has a large influence on the shape of shear curve of joint. Riveted joint with chamfer f=0 mm has higher stiffness than the joint with chamfer f=0.7 mm. The destruction of joint A0 (chamfer f=0 mm, Tab. 3) occurred at displacement s=1.65 mm. In the case of specimen A07 the joint was damaged at displacement s=4.2 mm. These results showed that the chamfer has an influence on damage mode of the rivet. The joint A0 (Tab. 3) has a destructive force F=998 N whereas the joint A07 – F=1030 N. Destructive force of joint A07 is about 3% higher than the maximum force registered for joint A0.

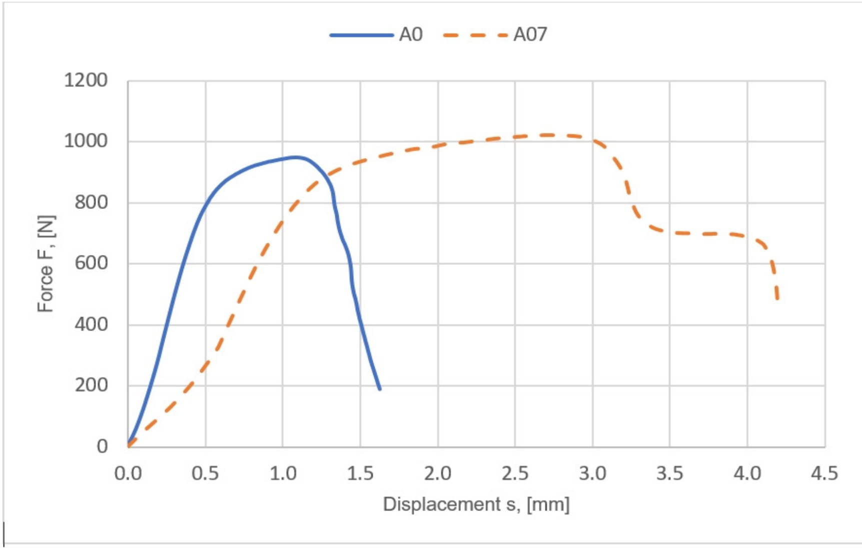

Fig. 5. Shear curves for one-rivet joints with size of hole chamfer f=0 mm and f=0.7 mm

Comparison of rivet fractures (Fig. 6) explains the difference in shear plots presented on Fig. 5. The rivet deformation presented in Fig. 6 a, b shows that the rivet (in joint with chamfer f=0 mm) was subjected to shear. In the case of joint with chamfer f=0.7 (Fig. 6 c, d) the rivet before destruction was subjected to more complex stress state (bending combined with shear).

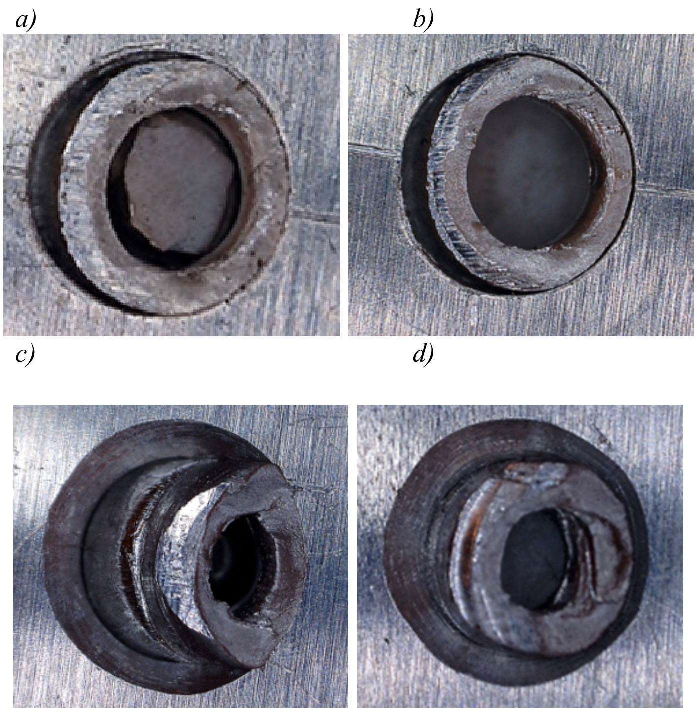

Fig. 6. View of damaged rivet in joint with 0 mm (a, b) and 0.7 mm chamfer (c, d)

Analysis performed for wider range of chamfer size (Fig. 7) showed that the highest value of destructive force (F=1185 N) was registered for joint A05 (with chamfer f=0.5 mm). The destructive force for joint A05 is about 18% higher than the maximum force for joint A0.

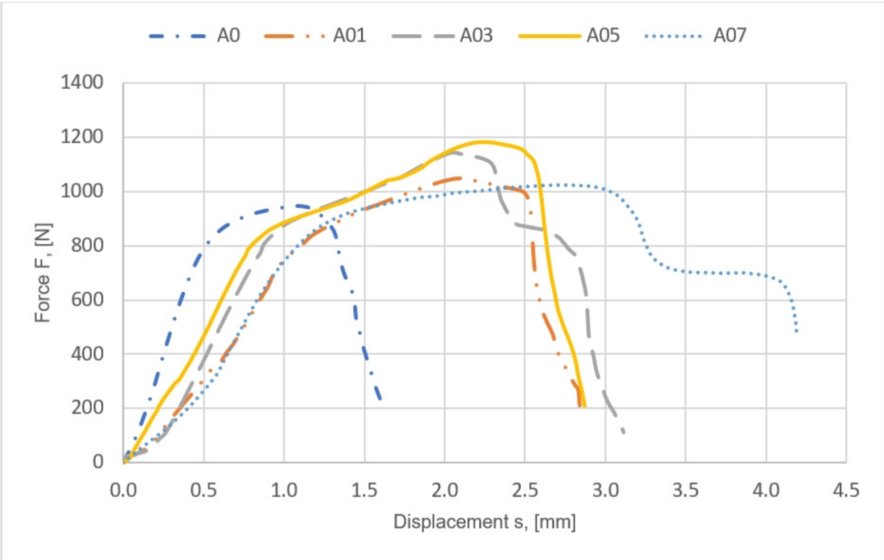

Fig. 7. Shear curves for one-rivet joints with different size of hole chamfer

In next part of the work the shear curves for one-rivet and five-rivet joints will be compared (Fig. 8). The shear curve for five-rivet joint showed that the destructive force is equal to 4800 N. The shear curve for five-rivet joint at beginning quickly increased to the value of about 400 N. Next (in displacement range of 0.5 – 1.3 mm) the value of force was constant. After displacement s=1.3 mm the linear increase of force (to the value of about 4000 N) was observed. At displacement s=3.5 mm the maximum force was registered on the shear plot.

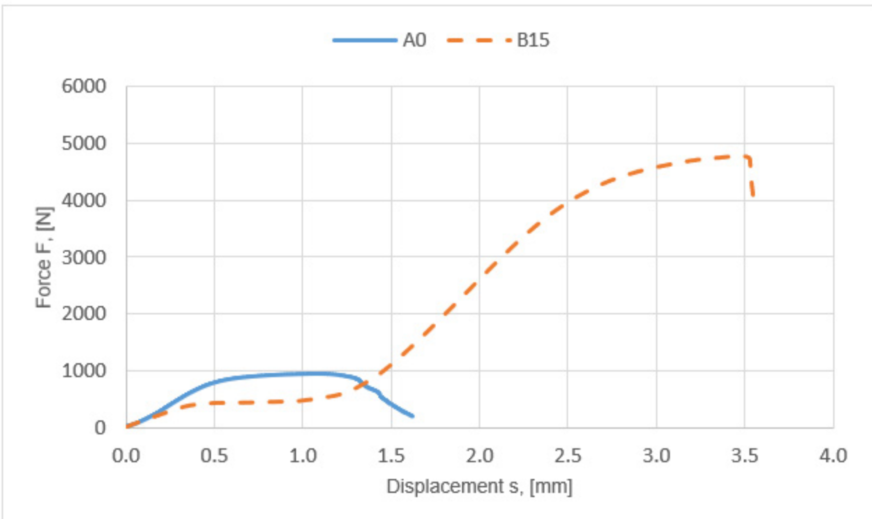

Fig. 8. The shear curves for one-rivet joint and single row five-rivet joint.

The shearing test results for joints with spacing p=15 mm (B15) and p=30 mm (B30) showed that rivet spacing has no influence on the strength of joint (Fig. 9). The difference is only in shape of both curves. The 5-row joint with spacing p=15 mm was damaged at displacement s=3.6 mm whereas the joint with spacing p=30 mm was destroyed at displacement of s=3.25 mm.

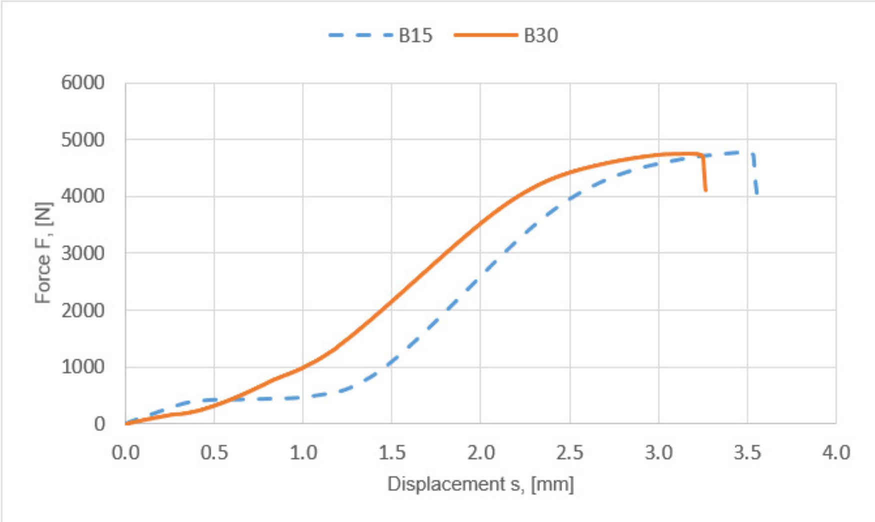

Fig. 9. The shear curves for five-rivet lap joints with two different rivet spacing

5. Conclusions

In this study the preliminary experimental investigations of riveted joints using blind rivets were performed. The influence of both the hole chamfer and the number of rivets on the destructive force of blind riveted joints were in detail analysed. After shear tests, the fractured rivets were magnified in order to explain the failure phenomenon of blind rivets. In results of performed investigations, the following conclusions were formulated:

1. The size of hole chamfer has a large influence on both the shape of shear curve of one-rivet lap joints and the deformation of rivet during damage.
2. Deformation of rivet in case of joint with chamfer f=0 mm shows that the blind rivet before damage was subjected mainly to shear. In the case of joint with chamfer f=0.7 mm the complex stress state (bending combined with shear) was observed.
3. The highest strength of one-rivet joint was registered for specimen with hole chamfer f=0.5 mm (1185 N). This value is about 18% higher than maximum force for joint without chamfer.
4. Results of preliminary tests made for joints with spacing p=15 mm and p=30 mm shows that the rivet spacing has no influence on strength of five-rivet joint.

In the future research work the extended experimental static tests of lap blind riveted joints will be performed. The results will be subjected to statistical analysis. The numerical simulation of blind rivet head forming and determination of both the preliminary stress and the destructive load for joints are also planned.

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